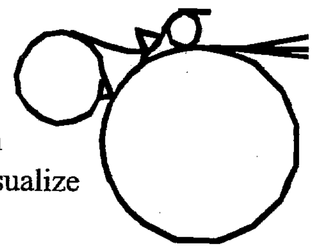
Investigation 19: Visualizing Smallest



Purpose:

The following model will allow students to see and actually participate in building a life-size model of a hydrogen atom, which will help them visualize the scale of what scientists study at Fermilab.

Objective:

This investigation will help students understand the vast empty areas within the atom or nucleus. By roping off occupied areas, one can visualize how atoms are arranged.

Materials:

Rubber stopper
Straight pin
Meter stick (school supply)
Two pieces of heavy string - 10 meters, 23 meters
3 BBs

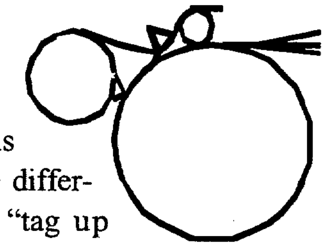
Procedure:

Note: Envisioning the vast distances of outer space may be a difficult task for middle school students. The distances in subatomic space are even more mind-bending, and therefore it is necessary to give students the opportunity to visualize and measure the relative distances involved with atomic and subatomic space.

1. Perform the following simulation models with your students by actually measuring or estimating the distances.
   A. If the nucleus of a hydrogen atom were the size of the head of a pin (1 mm), then the first electron in the atom would be an average of 10 meters away.
   B. If you allow the average BB (2 mm) to represent the size of a quark, then the proton (which is a hydrogen nucleus) would be represented by a circle 8 meters in diameter. (Use string or yarn to make this 23-meter-circumference circle.)
2. Using the quarks-in-the-proton model in B above, ask your students to estimate how far the electron in A above would now be from the 8-meter-diameter proton. (80,000 meters or about 50 miles)

   Note: There are three quarks in a proton. The quarks are assumed to be in rapid motion and held within the proton space by spring-like forces carried by other particles called "gluons." At any given point in time, a quark could be said to be occupying any part of this sphere. This is why we can say that the three quarks "fill" or occupy the entire empty space.
3. Any additional simulations that your students can experience will help them to develop an appreciation of the relative spaces and emptiness in the universe, both outer space and atomic space. (Scale modeling of the sun - earth - moon or the entire solar system are some other examples.)

Investigation 20: The Standard Model



Purpose:
Jargon is used in almost every aspect of science, and particle physics is no exception. Even in a sport like baseball, it is important to know the difference between a double play and a double. You need to know when to "tag up and run" and when to "tag the runner." Familiarity with the jargon of the Standard Model helps students feel a bit more like the scientist who studies the oddly-named particles that are members of the team.

Objectives:
Students will become familiar with the names of the six quarks: Up, Down, Strange, Charm, Bottom, and Top.
Students will learn about fractional charge and how quarks combine to make baryons.

Materials:
One deck of "Quark Cards" consisting of 20 Up, 20 Down, 5 Strange, 5 Charm, 1 Bottom, and 1 Top card. (Make these cards using the template provided on the page at the end of this section or have students to make the cards themselves.)

Note: Students will need to know a few things about how quarks combine to play this game. It may be best to write the following information on the board and have the game reinforce these ideas as play continues:

1. *Quarks have the names Up, Down, Strange, Charm, Bottom, and Top.*
2. *Quarks have either a +2/3 or –1/3 charge.*
3. *Baryons are always three quarks.*
4. *Baryons may only have integer total charges. Examples: a +2 total charge* $(+{}^{2}/_{3}, +{}^{2}/_{3}, +{}^{2}/_{3})$*, a +1 total charge* $(+{}^{2}/_{3}, +{}^{2}/_{3}, -{}^{1}/_{3})$*, zero total charge* $(+{}^{2}/_{3}, -{}^{1}/_{3}, -{}^{1}/_{3})$*, and a -1 total charge* $(-{}^{1}/_{3}, -{}^{1}/_{3}, -{}^{1}/_{3})$
5. *Some special baryons are up-up-down (a proton) and down-down-up (a neutron).*
6. *Quarks are not found in equal numbers. The rarest quarks are bottom and top.*

Procedure:
1. Explain the rules to the students and then help them as they work their way through the game. After a short time, the students will understand the basics of this investigation. The rules are:
   - Divide the class into teams. It is best to start with two or three students on each team.
   - Give each pair of teams one deck and shuffle the cards.
   - Have one member of each team draw five cards.
   - After the players on the first team look at their cards, they may consult and place any three cards into a baryon. When they do this they shout out "baryon" and the three quarks that make it up (for example: "charm, up, strange"). Then they announce the total charge of their baryon, and if it is a proton or neutron, name it for a bonus point.

- Next, they record the points for that turn according to the table below and replace the three cards by drawing three cards from the deck.
- The second team now takes its turn, and the teams continue alternating until the deck is exhausted. When the deck is gone, each team will have two cards left. These are simply discarded.
- The teams may wish to hold on to valuable cards so that they can create rare baryons with the relatively few strange, charm, bottom, and top quarks that are available in the deck.

Scoring Chart:

Baryon made of only up and down quarks	Bonus for naming a proton or neutron	Baryon containing one strange or charm quark	Baryon containing two strange or charm quarks	Baryon containing three strange or charm quarks
1 Point	1 Point	2 Points	4 Points	6 Points

Baryon containing one bottom or top quark	Baryon containing one strange or charm quark <u>and</u> one bottom or top quark	Baryon containing two strange or charm quarks <u>and</u> one bottom or top quark	Baryon containing two bottom or top quarks	Baryon containing one strange or charm quark <u>and</u> two bottom or top quarks
7 Points	9 Points	11 Points	15 Points	17 Points

2. At the end of the game, summarize the results and point out that the simple rules students used to build baryons are what scientists use in determining how nature works. This scheme is part of what is known as the "Standard Model."
3. Show the students the Standard Model chart. Discuss the components that make up our current understanding of matter.

Supplemental Investigation 20A: The Advanced Game

If the class enjoys the simple version of this game, consider adding a level of complexity by introducing antiquarks into the game. Make a second set of cards using the antiquark template with the same distribution as the quark deck (20 Antiup, 20 Antidown, 5 Antistrange, 5 Anticharm, 1 Antibottom, and 1 Antitop). To further distinguish them from the quark cards, consider making them on different colored paper.

Here are the additional rules for making antibaryons and mesons that students will need to know:

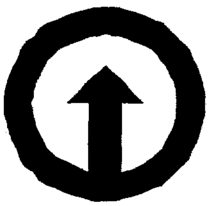
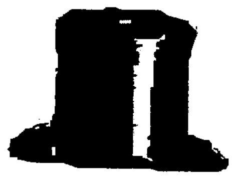
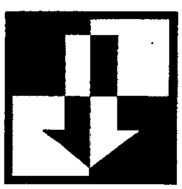
- Antibaryons are made exactly like baryons, only with three antiquarks instead of three quarks.
- Mesons are made from one quark and one antiquark. They must also have a total charge equal to an integer: -2, -1, 0, +1, or +2.

Meson Scoring for the Advanced Game (baryons and antibaryons are scored using the chart for the Basic Game):

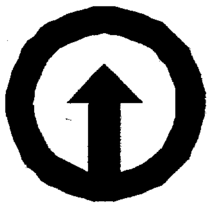
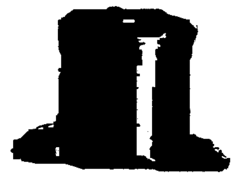
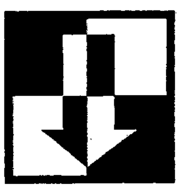
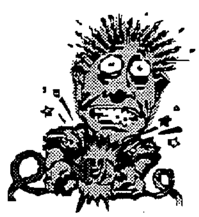
Meson made of only up and down (anti)quarks	Meson containing one strange or charm (anti)quark	Meson containing two strange or charm (anti)quarks
1 Point	2 Points	3 Points

Meson containing one bottom or top (anti)quark	Meson containing one strange or charm (anti)quark <u>and</u> one bottom or top (anti)quark	Meson containing two bottom or top (anti)quarks
5 Points	7 Points	12 Points

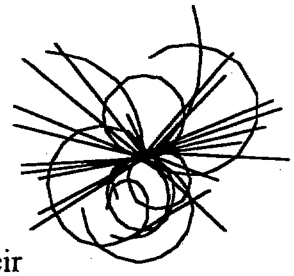
Template for Standard Model Quark Cards

+2/3 Up 	+2/3 Charm 	+2/3 Top 
-1/3 Down 	-1/3 Strange 	-1/3 Bottom 

Template for Standard Model Antiquark Cards

-2/3 Antiup 	-2/3 Anticharm 	-2/3 Antitop 
+1/3 Antidown 	+1/3 Antistrange 	+1/3 Antibottom 

Student Sheet Investigation 20: The Standard Model



Name____________________

Date____________________

Purpose:

Particle physicists have invented names for the objects they discover in their detectors. These names may sound a bit silly because you are unfamiliar with them. Today you will learn these names while you play a card game in class. It may be helpful to know several of the words you will use before the game starts.

Vocabulary List:

Quarks – There are six of these. Two of them, the up quark and down quark, make up much of the world around us.

Up Quark – very common, has a $+{}^{2}/_{3}$ charge
Down Quark – very common, has a $-{}^{1}/_{3}$ charge
Strange Quark – much less common, has a $-{}^{1}/_{3}$ charge
Charm Quark – much less common, has a $+{}^{2}/_{3}$ charge
Bottom Quark – very uncommon, has a $-{}^{1}/_{3}$ charge
Top Quark – the least common of all, has a $+{}^{2}/_{3}$ charge

Baryon – a particle made of three quarks (may have a +1 or zero charge)
Proton – a baryon made of two Ups and a Down
Neutron – a baryon made of two Downs and an Up

Playing the Game:

The rules for the game are best understood by playing an "open hand" where everyone starts to understand how points are accumulated. Your teacher will tell you a bit about baryons and quarks. In the beginning you may need to refer to these facts often. The rules for The Standard Model card game are:

- Divide into teams as your teacher directs.
- Shuffle the cards.
- Have one member of each team draw five cards.
- After the players on the first team look at their cards, they may consult and place any three cards into a baryon. When they do this they shout out "baryon" and the three quarks that make it up (for example: "charm, up, strange"). Then they announce the total charge of their baryon, and name it (if it is a proton or neutron) for a bonus point.
- Next, they record the points for that turn according to the table below and replace the three cards by drawing three cards from the deck.
- The second team now takes its turn, and the teams continue alternating until the deck is exhausted. When the deck is gone, each team will have two cards left. These are simply discarded.

- The teams may wish to hold on to valuable cards so that they can create rare baryons with the relatively few strange, charm, bottom, and top quarks that are available in the deck.

Scoring Chart:

Baryon made of only up and down quarks	Bonus for naming a proton or neutron	Baryon containing one strange or charm quark	Baryon containing two strange or charm quarks	Baryon containing three strange or charm quarks
1 Point	1 Point	2 Points	4 Points	6 Points

Baryon containing one bottom or top quark	Baryon containing one strange or charm quark <u>and</u> one bottom or top quark	Baryon containing two strange or charm quarks <u>and</u> one bottom or top quark	Baryon containing two bottom or top quarks	Baryon containing one strange or charm quark <u>and</u> two bottom or top quarks
7 Points	9 Points	11 Points	15 Points	17 Points

Answer the following questions after your game:

1. List the combinations of quarks that your team made into baryons in this game.

2. How many protons did you make?

3. How many neutrons did you make?

Section 5: HUMAN ELEMENT

Introduction and Purpose:

We often speak of the thrill of discovery in a historical manner. We remember the Wright brothers, Marie Curie, and, Albert Einstein, among countless others, many years after their work because of the contributions they made to science and our society. Who are the men and women that will enjoy a similar place in history in the next century? Where do they work and what do they do?

To answer these questions, we need to look to those who are pushing into new frontiers of human understanding. The men and women who try to discover what has never been known, to see what others have not seen. These are the men and women of Fermilab.

All the employees of the Lab share a common bond: They have come from all over the world, to work in jobs of all descriptions, in an effort to understand some of nature's deepest secrets.

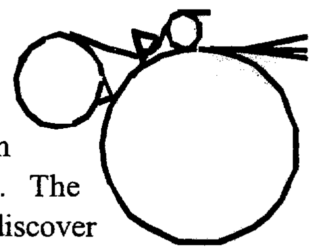
In this section, we will explore the excitement and pride that these teams of people feel as they combine their efforts in their search for understanding. Students will gain insight into the human element of the operation of Fermilab.

Objectives:

By the end of this unit, students will understand that:

1. Scientists find beauty in the work they do.
2. Fermilab has one of the premier accelerators in the world, which enhances the great pride staff members have in their work.
3. Experiments at Fermilab are of an enormous scale, often including hundreds of people.
4. Experiments at Fermilab are international efforts with men and women from all over the globe working together.
5. It takes many different kinds of workers, in addition to physicists, to make Fermilab operate smoothly.

Investigation 21: A Sense of Scale



Purpose:

One of the more challenging aspects of this unit is to help students gain the perspective that scientists are real people doing a job that they enjoy. The lab work, activities, and discussion questions simulate how scientists discover new knowledge about things that they cannot see. This new video will help students view these discoverers from a fresh, quite human point of view. It is important for students to realize these men and women choose their careers because they are excited about searching for the missing pieces that will someday help complete the Standard Model.

Objectives:

Students will realize that discovery and learning, although time-consuming and expensive at times, can be very rewarding.

Students will hear scientists discuss how they got interested in their various fields of study and what they have gotten out of it.

Students will gain the perspective that scientists are real people doing a job that they enjoy.

Materials:

A Sense of Scale

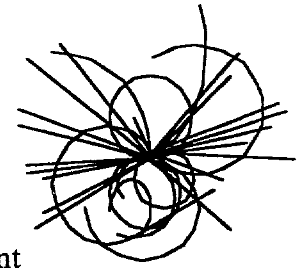
Student Investigation Sheet - *A Sense of Scale*

> *Note: Discussion questions and a teacher key are available in the teacher manual for this video. This aspect of this unit is an extremely important one on which to spend some time. Students will be solving problems for their entire lives, and realizing that problem-solving is an ability that all people in all walks of life need is a valuable lesson. They will also be working with all kinds of people and they must begin to build the respect for those relationships now. Being able to work successfully with many different types of people is a required skill in our society today.*

Procedure:

1. Discuss with your students why they think that people choose the careers they do.
2. Then ask them specifically why someone might want to become a physicist.
3. Discuss with your students what they think is meant by the "human element" of Fermilab. (We use it to refer to the variety of people here as it concerns their strengths and weaknesses, their likes and dislikes, etc.) How does it affect the work that the physicists do on a daily basis?
4. Read through the activity sheet with your students to prepare them better for what they will see in the film.
5. Watch *A Sense of Scale* video.
6. Determine ahead of time how the students will be held accountable for the video content. Will they take notes during the presentation, individually after the presentation, in small groups after the presentation?

Student Sheet Investigation 21: ***A Sense of Scale***



Name____________________
Date_____________________

Purpose:
One of the more challenging aspects of this unit is to help you as a student gain the perspective that scientists are real people doing a job that they enjoy. The lab work, activities, and discussion questions do a very good job of simulating how scientists discover new knowledge about things that they cannot see. This new video will help you view these discoverers from a fresh, quite human point of view. It is important for you to realize these men and women actually chose their careers because they are excited about searching for the missing pieces that will help complete the Standard Model someday.

Procedure:
After watching the video, follow your teacher's instructions regarding how you are to report on the content. It may be individually on this worksheet, through class discussion, through a small group effort on the worksheet, or in a completely different way. The major sections of the video are listed in capital letters.

1. "To understand nature, we have to break it down into its constituent components." How are scientists at Fermilab trying to do this?

RUNNING THE RING

2. The Tevatron is a ring almost four miles in circumference containing one thousand twenty-ton superconducting magnets buried thirty feet underground. The machine directs one trillion protons around the ring in a beam thinner than a human hair while electric fields are used to push the particles to higher energies. The energy in each proton and antiproton in the Tevatron is equal to that of six semi-trucks moving down a highway at 60 mph. Why do scientists need such an enormous machine that creates so much energy?

3. What is the main challenge for the physicists today as they operate this machine, parts of which were made in the 1970s?

STARTING THE BEAM

4. What is the purpose of each succeeding accelerator at Fermilab?

A PERFECT IDEA

5. "We are fascinated by the challenge of understanding the real world. We have a love of trying to figure things out. The more you think about something, the more you want to explore it." What qualities, personality traits and values do you think it takes to be a Fermilab scientist?

COLLISIONS

6. How long has it been since collisions like the ones occurring at Fermilab now have happened naturally?

7. Do you think it is important to spend money to create these collisions and study them? Why or why not?

DETECTORS

8. Fermilab's detectors are so massive and monitor so many collisions per second that it takes as many as 400 physicists to build and operate one. Yet, according to two of the physicists in the video, getting people to work together is as interesting a problem as getting the equipment to work correctly. Reflect on these two statements. How can so many diverse people make something like this work?

9. List and briefly describe the advantages of current electronic detectors when compared to older detectors such as the bubble chamber.

THE STANDARD MODEL

10. Name the six quarks and the six leptons that are part of the current Standard Model.

11. What is peer review? How can it benefit any science experiment?

UNFINISHED BUSINESS

12. "The whole idea in science is to make links between different phenomena." How does this statement relate to the work that is done at Fermilab?

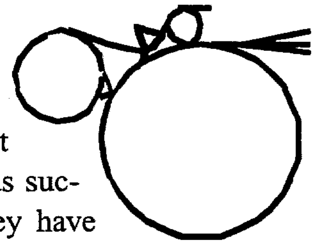
13. Summarize at least three of the remaining questions that face scientists at Fermilab. Areas for discussion can include: top quark, antiprotons, neutrinos, calculations

14. Fermilab scientist Chris Quigg said, "Ideas that I did not even know that I had came together." What do you think he meant?

15. Have you ever had an experience like Dr. Quigg's before? Describe it.

16. "The curiosity of children is why so many physicists work so hard." How curious are you about the world around you? What do you wonder about?

Investigation 22: Name that Career!



Purpose:
Fermilab is like a small city, in which many people have many different careers. Without each person in each job, the Lab would not function as successfully as it does. A common link between Fermilab workers is that they have great pride in what they do. Individuals truly believe that their individual and team efforts help make the lab productive. They are proud to contribute to the mission of a world-class institution and believe their work is important. They respect and value each other. In this activity, students will become more familiar with the variety of jobs people have at Fermilab.

Objectives:
Students will become familiar with the range of careers represented at Fermilab.
Students will understand that each job serves an important function at Fermilab.

Materials
Index career cards, one per student
Student Investigation Sheets - "Name That Career!"

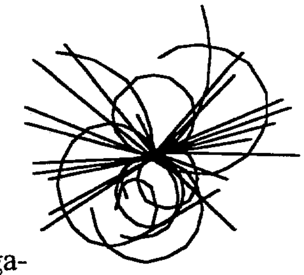
Procedure:
1. On each index card, before class begins, write the name of one Fermilab job from the list below.
2. Distribute one career card and one investigation sheet to each student. Ask the students not to share their identity with others.
3. Allow the students a moment to think about what that job might involve, where at Fermilab it might take place, how someone in that job might go about doing their work, etc.
4. Instruct the students to write their thoughts down on their sheet so that they can refer to them during the investigation.
5. Break your class up into groups of no more than six students per group.
6. Have one student from each group stand up. Allow the other students in his or her group to ask two questions each. The student will do his or her best to answer the questions. Then ask the other students to write down the name of the job they believe was being portrayed on their Student Investigation Sheets.
7. Continue this investigation until each of the students have represented their careers.
8. When the groups have finished their guessing, have them join the large group again. Ask .each student to tell the class what job they had represented.
9. Discuss the range of jobs and their importance to Fermilab. Use the Student Investigation Sheet questions as a starting point for this discussion.

Fermilab Jobs List:

Below is a table that represents several of the jobs at Fermilab. This list does not include every job and your students may wish to add other jobs based on people they know who work at the Lab.

Accountant	Director	Nurse
Activities Planner	Dormitory Manager	Painter
Architect	Educator	Photographer
Artist	Electrical Engineer	Public Relations
Astrophysicist	Experimental Physicist	Purchaser
Auto Mechanic	Fire Fighter	Refrigeration Expert
Bank Teller	Health and Safety Officer	Secretary
Biologist	Health Club Coordinator	Security Officer
Carpenter	Herdsman	Taxi Driver
Chef	Human Resources Expert	Telecommunications
Computer Engineer	Inventor	Theoretical Physicist
Construction Worker	Lawyer	Travel Planner
Custodian	Librarian	Videographer
Day Care Teacher	Machine Technician	Welder

Student Sheet Investigation 22: Name that Career



Name____________________
Date______________________

Purpose:
It takes a large variety of people to make Fermilab work. In this investigation, you will pretend to be a Fermilab employee and become familiar with the variety of jobs people have at Fermilab.

Investigation:

1. Look at the career you have been given. Don't share your career with classmates. Think about your job; for instance, where it might take place, with whom, and how you might go about doing your work. Write down some of your thoughts about your job here:

2. Have your research teams pick one person to be interviewed first.
3. You may ask this person two questions about their job.
4. After all research team members have asked their two questions, make the best guess you can and record the career on the lines below.
5. Repeat the process for all the students on your team.

Student	Job
____________________________	____________________________
____________________________	____________________________
____________________________	____________________________
____________________________	____________________________

(more space on next page)

Student	Job
____________________	____________________
____________________	____________________

6. Pick any three roles from number 5 and explain how you think they contribute to making Fermilab work.

7. Explain how Fermilab is very much like a city.

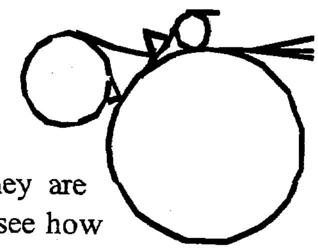
8. As a research team, discuss and answer the following questions.
   a) Fermilab has approximately 2,000 workers, many from countries other than the United States. Can you think of any challenges to having so many diverse people at one place? Can you think of any solutions to these challenges? List them.

<u>Challenges</u>	<u>Solutions</u>

   b) The first Fermilab director, Robert Wilson, wanted people of all kinds and all roles to talk to and learn from each other. There is a story at Fermilab that says that this is why he designed Wilson Hall (the main high-rise) to have too few elevators that move very slowly. Why might this work? Can you think of any other ways to get people to "mix?"

   c) Why might Fermilab need jobs such as a recreation coordinator, activities coordinator, lifeguard, arts series coordinator, etc?

Investigation 23: How Much Do You Really Know About Fermilab?



Purpose:

At this point in the Beauty and Charm unit, students may feel as if they are experts on Fermilab. The following investigation will allow students to see how much they really know or don't know about Fermilab, its people and its experiments.

Objectives:

Students will answer questions about Fermilab to assess what they know.

Materials:

Student Investigation Sheets - "How Much Do You Really Know about Fermilab?"

Procedure:

1. Have students answer these questions individually or in small research teams. If time is short, consider giving different teams different subsets of the questions.
2. After the students have completed the page, discuss the answers with short discussions of the concepts, as needed.

<u>How Much Do You Really Know about Fermilab?</u>
<u>Sample Answers</u>

1. What is the main scientific work done at Fermilab?
   Particle physics. Scientists are learning more about the structure and interaction of subatomic particles. Astrophysics is also done at Fermilab. Through this work, scientists are learning more about the correlation between the macrocosm of the universe and the microcosm of atoms.
2. Why is it important to do this scientific work?
   Pure research, learning more simply for the sake of learning more, adds to our knowledge of the universe and how it works. Humans are driven to find out more, answer mysteries and be able to predict based on their knowledge. Also, new technologies are always needed to push back the frontiers of knowledge. Many of these new technologies benefit society in a practical way.
3. How many people work on a Fermilab experiment?
   There are a wide variety of experiments going on at Fermilab at any given time. Small experiments may have twenty to thirty participants, while the collider detector collaborations number 300-400.
4. Why are there chalkboards in almost every office?
   To allow people at Fermilab the opportunity to record any thoughts at any time and to illustrate conversations as needed.

5. Why do you think there are flags from twenty-one different countries (including the United States) flying outside of Wilson Hall?

   To represent the countries that work in collaboration at Fermilab. There are actually scientists from more than twenty-one countries, so the twenty flags that fly in the line in front of Wilson hall are those of the twenty foreign countries with the most scientists present at the Lab.

6. How do you imagine the offices of Fermilab employees are decorated? Do you think there are differences between the office of a theoretical physicist, an astrophysicist, an experimental physicist, an educator, or a computer engineer? What might be some differences?

   Office decoration is a matter of individual taste. At Fermilab this may be "wacky" or austere or somewhere in between.

7. What is a quark? Why is the top quark so interesting?

   A quark is one of the fundamental constituents of matter. In an atom, three quarks make up each proton or neutron. There are six types of quarks: up, down, strange, charm, bottom, and top. The top quark was the last one to be discovered (at Fermilab in 1995) and the most massive by far.

8. What is used at Fermilab for treating cancer? Where does it come from?

   A beam of neutrons is used in treating cancer at Fermilab. The neutrons are the result of a collision of hydride (negatively charged hydrogen) ions with a target partway down the Linear Accelerator (also called the "Linac"). The beam that produces these neutrons is diverted from the Linac beam as it passes the Neutron Therapy Facility.

9. Why does Fermilab spend time and money caring for biological things, like bison and prairies, when it is a physics laboratory?

   There are many different answers to this question. One reason may be that the first director of the Lab, Robert Wilson, brought bison to Illinois to help restore and maintain the area's natural beauty. Another reason might be that many, including Dr. Wilson, felt that Fermilab should try to bring the land back to a pre-settlement condition with prairies and woods.

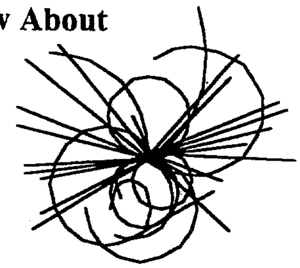
10. As more, higher-powered accelerators are built elsewhere in the world, what do you imagine the future will hold for Fermilab and its scientists?

    Fermilab will continue for many years as a research facility. It will also grow in its role as a teaching center for particle physics.

11. Why would someone want to be a scientist? What do they find satisfying about their work?

    Some enjoy finding out about something that no one has known before. Others enjoy discovering the laws of nature. Others enjoy the puzzles and challenges Fermilab provides. There are probably as many answers to this question as there are people at Fermilab.

Student Sheet Investigation 23: How Much Do You Really Know About Fermilab?



Name_________________________

Date__________________________

Purpose:

At this point in the Beauty and Charm unit, you may feel as if you are an expert on Fermilab. Answer these questions to see how much you really know or don't know about Fermilab, its people, and its experiments.

Procedure:

Answer the following questions:

<u>How Much Do You Really Know about Fermilab?</u>

1. What is the main scientific work done at Fermilab?

2. Why is it important to do this scientific work?

3. How many people work on a Fermilab experiment?

4. Why are there chalkboards in almost every office?

5. Why do you think there are flags from twenty-one different countries (including the United States) flying outside of Wilson Hall?

6. How do you imagine the offices of Fermilab employees are decorated? Do you think there are differences between the office of a theoretical physicist, an astrophysicist, an experimental physicist, an educator, or a computer engineer? What might be some differences?

7. What is a quark? Why is the top quark so interesting?

8. What is used at Fermilab for treating cancer? Where does it come from?

9. Why does Fermilab spend time and money caring for biological things, like bison and prairies, when it is a physics laboratory?

10. As more, higher-powered accelerators are built elsewhere in the world, what do you imagine the future will hold for Fermilab and its scientists?

11. Why would someone want to be a scientist? What do they find satisfying about their work?

Section 6: FIELD TRIP

Introduction and Purpose:

Fermilab is a unique research facility. Hundreds of men and women combine their efforts to imagine, construct, and operate machines unlike any others on Earth. Many of the people working at Fermilab proudly represent their home country as participants selected from many hundreds of candidates to come to Illinois to work.

Fermilab has held the position as the world's highest-energy particle accelerator for longer than any other lab over the last quarter century. This fact alone makes it the premier place to study particle physics.

It is a unique opportunity to visit a facility of this reputation. It is an unforgettable experience to speak with scientists and other workers at the lab. In your trip to Fermilab you will meet the men and women of Fermilab, see their experiments and enjoy a visit to the Leon M. Lederman Science Education Center.

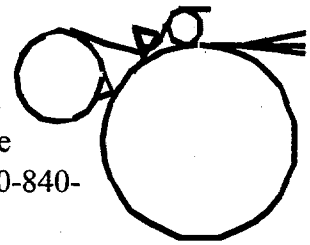
This Center was constructed with students in mind. Particle physics is made "kid-friendly" through interactive experiments designed to teach some of the critical ideas covered in this course.

Objectives:

At the completion of the *Beauty and Charm* field trip, the students will have:

1. Transferred knowledge gained in classroom models to understanding the activities at Fermilab.
2. Seen first-hand several of the special tools used by Fermilab scientists.
3. Acquired some familiarity with how these tools work.
4. Met and talked with a Fermilab scientist.
5. Experienced some of the unique ambiance ("flavor") of Fermilab. This may include its size, people, art, connections with nature, general aesthetics, casual atmosphere, writing opportunities, and connections with history.

Before a Trip to Fermilab



Normally, students of junior high/middle school age are not allowed group tours of Fermilab. Your use of this instructional unit may provide an opportunity for a tour. Contact the Fermilab Education Office at 630-840-5588 for more information.

It is imperative that any teacher who is planning to bring students to Fermilab for a field trip teach this unit to his or her students. Students who have not studied the terminology, purpose and processes intrinsic to Fermilab will not be able to benefit from the tour and can potentially create behavior problems for docents or staff.

If available, before you visit Fermilab, show the Hawkhill sound filmstrip titled *Fermilab.* This will aid your students in the overall understanding of what they will experience during their visit. Other related videotapes are available for purchase through the Fermilab Office of Public Affairs.

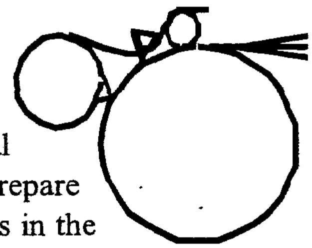
You may also supplement classroom activities with various articles and puzzles found in the *Quark Quest* newspaper, which is available through the Lederman Science Center. Call 630-840-8258 for details.

Work with your students in advance to prepare questions to ask the docent guide and physicists while at Fermilab.

Preview a map of the Fermilab site to help students recognize major features on the trip that they will be able to see from the high-rise or when riding on the bus.

After the trip, encourage your students to take a parent to Fermilab and its Leon M. Lederman Science Education Center to explore further on their own.

Investigation 24: Beauty and Charm Student Tour



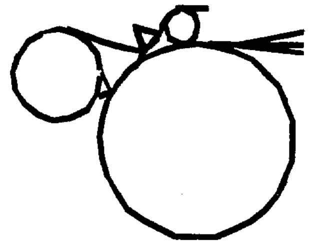
Purpose:
Seeing first-hand where science is done can be a powerful and meaningful experience for students. It is important that you make every effort to prepare them for this important part of the program. Student preparation begins in the classroom and will be completed on site.

Objective:
Students will see the machines and meet the men and women who build, operate and understand these machines and the secrets the machines reveal.

Materials:
Students may wish to bring paper and pencil to take notes.
Cameras are welcome on tours.

Procedure:
1. Before leaving on the field trip to Fermilab, explain to students that Fermilab is a working laboratory. The machines students will see are being used in experiments even as they are there. The men and women at the Lab are involved in current research and the students' visit *is a rare chance to glimpse what it is like to be a scientist in this decade.*
2. Stress that the students must stay with the group and follow all directions given by the Fermilab docents (tour guides). Safety is of prime importance, so the students should not touch anything nor should they enter any areas unless they are directed to do so.
3. Upon arrival, the docents will give some reminders of safety procedures and general group directions. Please make sure the students listen.
4. Students will visit the Lederman Science Center with docents and have an opportunity to work with the exhibits in this Center. Docents will provide details of this portion of the visit.
5. Students will visit the first two stages of the acceleration process with docents. The first two accelerators are called the Cockcroft-Walton and the Linear Accelerator, or "Linac." If time permits, the students may also see the Main Control Room.
6. The students will go to the 15th-floor exhibits in Wilson Hall with docents. Here they will have an overview of the entire Fermilab property and the accelerator complex, which the docents will explain.
7. Students will meet with a scientist at the Lab. Here they will be able to ask questions they have prepared in advance, as well as any that have occurred to them during the day.
8. A very good follow-up activity is to have the students process what they saw and heard about when they get back to school. Some teachers may prefer a journaling activity, while others will prefer a verbal discussion. In any event, it is good practice to let the students sort through the information they have acquired when they get back to school.

Field Trip Checklist and Chaperone Guide



In an effort to make the field trip as successful as possible, there are several things that you should know. We include the following as a guideline. You may discover that other things work well for your situation.

Teacher Checklist:

1. Student List – Assign students to groups of three or four before the trip.
2. Parent Permission Sheets (district or school provided)
3. Emergency Sheets (district or school provided)
4. Extra Handouts (if you wish for them to have something)
5. Call a local restaurant if you are intending to eat there.
6. If you are planning to eat at Wilson Hall, check with Fermilab personnel first. (Call 630-840-5588.)
7. Call the Docent Coordinator at 630-840-5058 two or three days prior to the trip to find out what type of a program they are currently running. (No surprises!)
8. Each student should bring:
   8.1. Journals (each with a pre-written question for the scientist).
   8.2. Pencil or pen.
   8.3. A lunch (unless you are making provisions at another location).
   8.4. Clothing appropriate for travel outside from the Lederman Science Center to Wilson Hall.

Chaperone Information:

Your job today is important for a number of reasons. You and your students will be visiting a place of business where people are actually performing scientific experiments during your visit. There is a certain amount of danger inherent in this situation so you need to be alert to where the students are at all times. Do not let them wander off!

The students will be asked to do several experiments during their visit. You need to help them (primarily by listening to the docents and by reading directions to them) as they move through the Lederman Science Center. Please try to avoid getting so involved in the experiments that you lose track of the students you have been asked to watch.

The teacher will be asking you to work with the students, talk with them and be a helper. However, please do not answer all their questions, but simply help them discover the answers to the questions through their own exploration.

Rarely, a student may be disruptive on the trip. Should this happen, you may be asked to bring that student to the teacher or you may be asked to shadow that student. The Fermilab docents will not tolerate poor behavior and it is always better to shadow a troublesome child than to sit on the bus with that child while the rest of the class enjoys the trip.

Finally, enjoy your day with the students. Watch them. They have a natural curiosity and are not afraid of topics that adults often think are too difficult. You will enjoy your day much more if you catch the excitement the students have when learning in a new setting.

Content Background for Teachers

What is particle physics?

Dr. Leon M. Lederman, recipient of the 1988 Nobel Prize in physics and former director of Fermilab, has defined physics and particle physics in the following terms:

> Physics is essentially a cultural activity . . . there is a need to know—there is a heritage handed down—a vision that the human brain can "solve" or put into rational order the physical problems of our own existence, starting with the creation of the universe in a big bang and predicting its evolution to the infinite future.
>
> Physics is thought to be very difficult by most physicists, **but** this is the creation of new physics. Understanding of what has been done requires no more patience and intelligence than finding out what has been done in art, music, and literature. Physics is vital to a large number of other disciplines for which it furnishes either the basic laws or the instruments or both.
>
> Particle physics is a search for the most primitive, primordial, unchanging and indestructible forms of matter and the rules by which they combine to compose all the things of the physical world. It deals with matter, energy, space, and time.
>
> The objectives of particle physics are to identify the **most simple** objects out of which all matter is composed and to understand the **forces** which cause them to interact and combine to make more complex things.

Particle physicists use basic terms and concepts when describing their research. Some of those terms and concepts are summarized below, not necessarily to be taught to students, but to provide a background for the teacher for questions that may arise. Other information is presented in the Teacher Notes associated with individual activities. (The *Focus on Fermilab* booklet available through Fermilab provides a more detailed introduction. Also you may wish to consult one of the references listed at the end of the Background section.)

Some Particle Properties

A particle, increasing its speed because of some force acting on it, gains energy of motion. An electron (negatively charged) gains **one electron volt** (eV) of energy in accelerating through a vacuum from the negative end to the positive end of a one-volt battery. The one eV of energy is given up to other particles as the electron crashes into the positive end.

A proton (positively charged) traveling from positive to negative pole through the vacuum would also gain one eV of energy and give it up in its collision with particles in the negative end. This proton collision is similar to the proton beam collision with a target at Fermilab, but at Fermilab the proton energy is much greater.

As a particle's speed approaches the speed of light (almost 300,000,000 meters per second), most of the energy it gains is not in the form of greater speed, but greater mass. When the particle slows down or collides with another particle, the extra mass may be converted back to energy of motion or it may form new particles. For example, a proton at its maximum speed in the Fermilab accelerator has more than 800 times the mass it had when not moving (rest mass). This mass may appear as new particles after a collision.

Since energy can become mass and mass can become energy (from Einstein's famous equation $E=mc^2$), both are aspects of the same thing. Since subatomic masses are so small, it is easiest to express them in the very small electron-volt (eV) unit.*

*The approximate conversion factors are:

1 gram = 6×10^{26} million electron volts (MeV)
1 electron volt = 1.6×10^{-33} grams
1 MeV = 1.6×10^{-27} grams

Every particle has either no rest mass or a rest mass that is unchanging. For example, an electron's rest mass is .511 MeV, a proton's is 936.2 MeV, and an upsilon's is 9402 MeV. A photon (a particle of light) has no rest mass, only mass when in motion at its normal speed—the speed of light.

Every particle is either neutral or has an electrical charge that never changes. The charge of an electron is negative. Its magnitude is often used as a unit of electric charge (e). An α-particle (alpha-particle—2 protons and 2 neutrons—see Investigation 11) has 2e positive charges. (The quantity of charge "e" exists in both positive and negative form.)

There are other quantifiable properties of particles including spin and magnetism. The quark, considered to be one of the most fundamental particles, has additional properties given fanciful names such as color and flavor.

The Need for Large Accelerators

In order to study small particles, scientists must generate a high-energy beam of particles. The reason is that the higher the energy, the more finely penetrating and discriminating a particle probe can be and the smaller the structure that can be studied. Also, the more energy (mass) available to a particle or particles in a collision, the more new or more massive particles can be created by that collision of the particle with a target particle.

Fermilab produces charged particle (proton) beams with billions of electron volts of energy in order to study the makeup of particles in the tiny, dense nuclei of atoms. Fermilab's 1985 modification to the four-mile circumference Main Ring accelerator allowed Fermilab scientists to accelerate protons to 1,000 billion electron volts (expressed 1,000 GeV, G for giga- meaning 10^9), which is equivalent to one trillion electron volts (expressed 1 TeV, T for tera- meaning 10^{12}). The modified accelerator is thus called the Tevatron. The most recent (1999) improvement is the addition of the Main Injector. This will increase the luminosity (number of collisions per second) by a factor of five and allow both types of Fermilab experiment, "fixed target" and "collider" to run simultaneously.

Particles were first used to probe the inside of atoms in about 1910. Ernest Rutherford used naturally emitted α-particles from a radioactive source to bombard thin gold foil. He found that most α-particles passed through the foil undeflected, while a few bounced back at sharp angles, apparently due to hitting tiny, solid objects. This was the first experimental evidence that there was a small, heavy, positively charged core to the atom and that the rest of the atom was mostly empty space.

In the 1930s, 40s, and 50s the study of the nucleus (nuclear physics) grew and included the details of the patterns of radioactive decay of nuclei and the forces that hold the nucleus together. Particle physics, also known as high-energy physics, developed as a branch of nuclear physics to investigate the structure of nuclear particles using high-energy particle probes.

The first circular particle accelerators were small instruments called cyclotrons ranging in diameter from a few inches to a few feet. Two fundamental limitations on particle speed required that larger accelerators be built to create the higher-energy particle probes necessary to study nuclear particles.

1. In circular accelerators such as Fermilab's, particle paths are made to curve by a magnetic field passing vertically down through each section of the accelerator ring. The faster the particle, the stronger the magnetic field must be to keep the particle in the fixed radius ring. However, there are upper limits (some of them financial) on how strong a magnet can be. By making the circle larger, the particle can go faster while the magnetic field strength remains the same.

2. When charged particles travel in curved paths they give up energy in the form of radiation such as light. The sharper the curve the particles are forced to turn, the greater the energy lost to radiation. At some point, all the new energy being input to the accelerator to push the particle faster will be immediately radiated away with no net gain in particle energy. By making the curve more gentle (larger circle), the radiation loss is less and the particles retain more energy.

Since forcing the charged particles to follow curves seems to be the source of problems in accelerating a particle, why not accelerate them in a straight line? This is done in the second-stage accelerator, called the Linac, at Fermilab, and on a larger scale at the Stanford Linear Accelerator Center in California. However, the advantage of the circular accelerator is that each time around the circle the particles can be given a new push, similar to the way a playground merry-go-round can be given many pushes by a person standing in one place. To gain the equivalent number of pushes, a linear accelerator would have to be incredibly long and expensive.

Each bunch of protons in Fermilab's Tevatron is pushed 40,000 times each second by passing through just one "pushing station" on each four-mile trip around the circle. The fully accelerated protons travel at more than 99.999% the speed of light and have more than 800 times their rest mass. The distance the proton travels in one second is four miles times 40,000 which is 160,000 miles, or the equivalent of almost $6^1/_2$ trips around the earth.

The Present Theory of Fundamental Particles and Forces

Before World War II, it was known that the nucleus was composed of closely packed protons and neutrons, but little was known about the "strong force" that kept them together. From 1950 to 1970, scientists built accelerators which were designed to probe nuclei with higher speed and more energetic, charged particles such as electrons and protons. The result was the discovery of hundreds of new particles and the determination of their properties.

In 1963, Murray Gell-Mann proposed a theory that a major group of these particles, called hadrons, could be thought of as made from a few, more fundamental particles, called quarks. Protons and neutrons are members of the hadron group.

Gell-Mann proposed quarks to be the simplest, irreducible, structureless building blocks of hadrons. The Quark Hypothesis states that quarks in combinations of two or three make all the observed hadrons. In 1963, the three known quarks were named: up (u), down (d), and strange (s). A neutron is composed of three quarks, u d d; a proton, u u d; and a lambda, u d s. In 1974, the existence of the charm quark (c) was revealed and in 1977, Leon Lederman and his colleagues at Fermilab uncovered the fifth quark, bottom (b). The final quark, top (t), was proposed almost immediately after the discovery of bottom to account for additional particle properties, and was discovered at Fermilab in 1995.

Electrons, neutrinos, and a few other particles make up another group of particles called leptons. Leptons are not thought to be divisible and are not made up of quarks.

The results of particle physicists' theoretical and experimental work up to 1995 might be summarized this way:

> All matter is thought to be made up of quarks and leptons and the force carriers through which they interact. There are six quarks. (Each comes in three "colors," making 18 particles, and each has an antiparticle, making 36 quarks in total.) The six quarks are named up (u), down (d), strange (s), charm (c), bottom (b), and top

(t). (The last two are sometimes fancifully referred to as "beauty" and "truth.") The top quark was discovered at Fermilab in 1995. All six quarks have been confirmed through indirect observations, but not isolated as individual particles.

The other six particles (also appearing in antiparticle form, making 12 total) are the leptons. These include electrons (e), electron neutrinos (ν_e), muons (m), muon neutrinos (ν_m), tau particles (t), and tau neutrinos (ν_t).

The twelve particles (48 in all if you include colors and antiparticles) are subject to the four fundamental forces of nature. These forces are gravity, electromagnetic, strong, and weak. Each force is defined by the way it interacts with particles to build up composite form of matter: protons, neutrons, nuclei, atoms, molecules, planets, stars, and so on.

Each of the forces has a strength, a range, and a "carrier" particle as outlined in the table below.

Force: Weakest to Strongest	**Range**	**Carrier**	**Observed**
Gravity	All Distances	Graviton	No
Weak	Nuclear Distances	W^+, W^-, Z^0	Yes (1983)
Electromagnetic	All Distances	Photon	Yes (1923)
Strong	Nuclear Distances	Gluon	Yes (1978)

One of the fundamental quests of the Fermilab scientists is to find an underlying link to unify the four basic forces. This Unification Theory would link all particles and forces into a coherent and simple description of nature.

In order to "observe" the basic particles of matter and collect data that may be of use toward theory development and perhaps the Unification Theory, physicists need particle probes with great amounts of energy. The protons with 1,000 GeV (1 TeV) energy now available in Fermilab's accelerator will help in this quest. By creating head-on collisions between these protons and 1,000 GeV antiprotons (generated earlier in stationary target collisions in a nearby storage ring) circulating in the opposite direction, 2,000 GeV collision data will be generated.

The main purpose of Fermilab and other large particle accelerators is to collect data that will support or refute theories. The need for new and better data is continuous. Numerous experiments remain to be done and each new theory and the related attempts at experimental verification inevitably lead to new insights as well as new questions about the most fundamental particles and forces that form all matter.

Quantum Mechanics

Perhaps more than any other theory of the past century, quantum mechanics forced us to re-evaluate how we view the world. It shook Einstein and totally changed the way scientists view the universe by creating a world of probability rather than definite answers.

Quantum mechanics is most prominent in the smallest particles in our world. As the view widens from the quark level on to the molecular level, quantum effects are less important. In fact, by the time we get to objects the size of the head of a pin, the effects are almost always impossible to discern.

In the very tiny world, we discover that objects effervesce into and out of existence without having a great effect on the larger object of which they may be a part. Particles move, not as balls vibrating or bouncing from place to place, but rather as clouds or waves whose position is never quite well known.

Even energy follows this pattern. One cannot turn up the energy of an atom, for example, so that it gradually increases. Instead the energy increases in hops or jumps. These incremental changes are known as "quantized" changes and are characteristic of the very small world of quarks and leptons.

In a simple view, one can think of objects and energy existing in certain states but not existing in adjacent states. Movement between these discrete states is accomplished by a "hopping" from one state to the next. While the jump is occurring, the particle or energy cannot be defined and is thus not really there.

This unnerving world of "jumping" particles and energies is what quantum mechanics is all about, and the lack of clear definition is troublesome to most. In an effort to rectify the fact that existence is so fleeting, scientists have found help in the use of probability. In other words, the probability that a particular object or energy will be found in a particular locale is often calculated and tied to the existence of the objects themselves.

This idea was even troublesome to Albert Einstein who said, "God does not play dice with the universe."

Accelerators at the Lederman Science Education Center

At Fermilab, the machine that is used to bring particles to great energies is called an accelerator. This marvelous collection of wires, pipes, magnets and metal is a testament to this important process of changing speed. The understanding of acceleration itself is critical to a clear understanding of what is done at Fermilab.

Acceleration, the change in speed with respect to time, is at the very core of exploring modern particle physics. The interactive displays in the accelerator room at the Leon M. Lederman Science Education Center will assist students in understanding acceleration and accelerators.

Detectors at the Lederman Science Education Center

Our senses of taste, touch, smell, hearing and sight allow us to understand the world around us. As we go through each day, these are our guides to the physical surroundings. They help us decide where to go, what to do and how things operate.

When we lose part or all of one of these senses, medical doctors can provide help. Many people have hearing aids or use glasses to help them extend their own abilities to explore the world. In a sense, that is exactly what particle physics detectors do. They extend our eyes or ears to the physical world that is too small for us to see.

A Geiger counter marks the decay of a nucleus with an audible "tick." We interpret many things from this sound without ever seeing the actual cause of the "tick" we have encountered. In a similar way, complicated computer drawings of a collision of particles (detector plots) allows our eyes to interpret an "event" whose participants are the smallest known particles in the universe.

Scientists become so familiar with detector plots that they know them to be as real as the markings on this page are to those reading them through lenses. In other words, glasses and particle physics detectors are in many ways different sides of the same coin. They both help us see clearly a world that would otherwise be hidden to us.

There are many types of detectors at Fermilab, but they all have the same goal: to allow scientists the opportunity to explore worlds too small or to fleeting to be seen otherwise. The interactive displays in the Detector room at the Leon M. Lederman Science Education Center will assist students in understanding the importance of detectors.

Collisions and Scattering at the Lederman Science Education Center

Everyone has been in the situation where he or she has had to describe what took place in a short period of time. A particularly useful example of this might be an automobile collision. In this case, there is seldom a camera available to film exactly what took place. Rather, the aftermath of car parts, broken and scattered, along with tire marks and other debris must tell the story.

In court, police and lawyers alike try to make sense of these details to understand the collision. Ultimately, the sound judgement of the jury or judge is called into play as a final decision is reached. The collision is determined to be of a particular nature with cars going particular directions at certain speeds and the results point to a better understanding of what happened to cause the collision.

Particle physicists make use of these same strategies as they look at the debris (in the form of energy) left in detectors after a particle collision. They try to decipher the clues left behind to understand the nature of the participants in the collision, and in some cases, they even try to understand what new particles are created in these collisions.

In particle physics, the most exciting aspect of looking at scattered debris is that in this debris, new particles are sometimes found. A new type of matter never before seen may be created in the collision of two well-understood particles. This is the real "sleuthing" of particle physics. It is in this searching that these men and women gain deeper understanding of our world and the particle species found here.

This exciting search for nature's secrets is highlighted in the Methods room of the Leon M. Lederman Science Education Center. The interactive displays in the room assist students in understanding the process of looking through debris for unusual or familiar patterns to understand our world.

GLOSSARY

This glossary is provided for teacher reference only and is not intended for direct teaching or memorization.

Accelerator - A machine that serves as a source for a well-defined beam of high-speed particles for studies in nuclear science and high-energy (or particle) physics.

Antiparticle - Particle with the same mass but opposite charge as another particle under normal conditions.

Atom - The basic structural unit of each of the elements in the Periodic Table. Atoms are composed of protons, neutrons and electrons.

Bohr Model - Model of the atom proposed by Niels Bohr in 1913. It showed electrons in fixed orbits around the nucleus, but acting in some ways like waves.

Bubble Chamber - A container filled with a liquid under low pressure so that a moving, charged particle initiates "boiling" in the liquid along its path. This track of bubbles is recorded on stereophotographs.

Circular Accelerator - Scientific machine in which particles are accelerated as they travel around a circular path.

Electromagnetic Force - Attraction or repulsion due to the electric charge of matter.

Electron - A point-like particle with a negative charge; member of the lepton group and thus not divisible into more fundamental particles.

Electron Cloud Model - Current model of the atom in which electrons are located in regions according to rules of probability rather than in defined orbits.

Electron Volt (eV) - The amount of energy given to an electron as it is accelerated from the negative end to the positive end of a one-volt battery.

GeV - billion electron volts (10^9)

Gluon - Carrier of the strong force which binds quarks together in protons, neutrons, and other particles.

Graviton - A massless particle whose exchange between masses is thought to produce the gravitational force.

Gravity - The attraction of mass to all other mass. Gravity is the weakest known force in nature at normal energies.

Hadron - Particles made up of two or three quarks bound together by the strong force.

keV - thousand electron volts (10^3)

Lepton - An indivisible fundamental particle. There are six leptons plus their antiparticles.

Linear Accelerator - Also called a Linac, a scientific machine in which particles are accelerated in groups along a straight line path.

Macrocosm - A large system.

Microcosm - A very small system, such as an atom.

Neutrino - A lepton of very small mass and zero electric charge.

Neutron - A particle with mass slightly larger than that of the proton, but with zero electric charge; a neutron is a hadron and is made up of three quarks.

Nucleus - Positively charged central core of an atom that is responsible for almost the entire mass of an atom. It is made up of protons and neutrons.

Photon - A particle with zero rest mass that transmits the electromagnetic force. Light is made up of photons whose energy depends on the wavelength of light.

Proton - A positively charged particle 2,000 times more massive than an electron that, with neutrons, forms all nuclear matter; a proton is a hadron and is made up of three quarks.

Quark - A fundamental particle. There are six quarks (but only five have been observed) plus their antiquarks. Each quark and antiquark exists in three "colors."

Strong Force - Force that binds quarks and holds the nucleus of an atom together. It is the strongest force in nature.

Superconductor - A metal that when cooled below a critical temperature exhibits no electrical resistance. Twenty-five elements and many alloys and compounds have been found to be superconducting. The critical temperatures range from .002 K to 18 K (-273 °C to -255 °C).

Unified Field Theory - The single physical principle or law that would explain the link between the four known forces of nature.

Weak Force - The interaction that controls radioactive decay.

MeV - million electron volts (10^6)

TeV - trillion electron volts (10^{12})

PROCESS SKILLS

Each section of the unit lists inquiry process skills that students might use in performing the section's activities. Process categories become increasingly interrelated with corresponding development of other processes and thus form a web of interrelated skills. The following web and definitions of process skills are to assist in understanding their importance in this unit.

WEB OF INQUIRY PROCESSES

Observing: Identifying objects and object properties.

Communicating: Transmission of information to others and describing a variety of objects and changes.

Classifying: Categorizing of objects and events.

Using Numbers: Ordering and counting, using arithmetic operations and recognizing powers of ten.

Measuring: Identifying and ordering lengths, weights, speeds, and other properties.

Inferring: Drawing relationships among things observed and generalizing upon experiences.

Predicting: Simple estimates and extrapolations.

Controlling Variables: Identifying and manipulating the factors that will or will not affect the outcome of an experiment.

Defining Operationally: Defining a word or concept in terms of an operation (measurement or task) that is performable and common to all of those using it.

Interpreting Data: Simple description based on previous experiences, especially numerical data analysis.

Experimenting: Trial and error manipulation of discovery activities.

RESOURCES

Student Books:
Asimov, Isaac; *How Do We Find Out About Atoms?* Walker, NY, 1976.

Asimov, Isaac; *Inside the Atom*, Abbelard Schuman, 1976.

Berger, Melvin; *Atoms, Molecules, and Quarks,* Putnam, NY, 1986.

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Gallant, Roy; *Explorers of the Atom*, Doubleday, NY, 1974.

Harber, Heinz; *Our Friend the Atom*, Simon and Schuster, NY, 1956 (Disney).

Hobart, Ellis; *Knowing the Atomic Nucleus*, Lothrup, Lee, and Shepard, NY, 1973.

Lampton, Christopher F.; *Particle Physics: The New View of the Universe*, Enslow Publ., Hillsdale, NJ, 1991.

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Larsen, Egon; *Atoms and Atomic Energy*, Golden Press, NY.

Leeds, Rosalind; *Introducing the Atom*, Harper and Row, NY, 1967.

Teacher Resources: Books:
Carrigan, Jr., Richard A. and W. Peter Trower, *Particles and Forces at the Heart of the Matter*, W.H. Freeman and Company, NY, 1990.

Pagels, Heinz, *Perfect Symmetry*, Simon and Schuster, 1985.

Hawking, Stephen, *A Brief History of Time*, Bantam Books, 1988.

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Teacher Resources: Articles:

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Begley, Sharon, "The Biggest Machine Ever," *Newsweek*, April 22, 1985, v. 105. p.56, Ill.

Bronson, Gail, "Dancing on the Head of a Pin," *Forbes*, April 6, 1987, v. 139, p. 152.

Browne, Malcomb, "Atom-Smashing Now and in the Future: A New Era Begins," *New York Times*, February 3, 1987, v. 136, p. 15, Ill.

Cool, Norman, "A Crystal Clear View of the Nucleus," *New Scientist*, March 31, 1988, v. 117,p. 44, Ill

Fisher, Arthur, "Seeing Atoms," *Popular Science*, April 1989, v. 234, pp. 102-107, Ill.

Hill, Chris, "Guage Bosons: "The Ties That Bind," *The Science Teacher*, October 1982.

Hill, Chris, "Quarks and Leptons: It's Elementary," *The Science Teacher*, September 1982.

Jones, Glyn, "The Phantom of the Atom," *New Scientist*, January 28, 1988, v. 117, p. 56, Ill.

Klose, Kevin, "Old Prairie, New Frontier." *Washington Post*, March 16, 1985, v. 108, p. A3, col. 4.

Lederman, Leon (interview) *Omni*, pp. 100-110, 158.

Quigg, Chris, "Elementary Particles and Forces," *Scientific American*, April 1985, v. 252, no. 4, p. 84-95.

Sullivan, Walter, "In Search of the Elusive Atom," *Modern Maturity*, v.28, August/September 1985, p. 56, Ill.

Wilson, Robert R., "Particle Accelerators," *Scientific American*, March 1978, v. 198, no. 3, pp. 64-76.

Wilson, Robert R., "The Batavia Accelerator," *Scientific American*, February 1974, v. 230, no. 2, pp. 72-83.

Teacher Resources: Audio-Visual:

The following pricing and availability information is current as of October 1993.

The Atom, VHS, 36 minutes, color, 1992.

On-location searches for the secrets of the atom. Part 1: "How we found out about atoms" and Part 2: "What is an atom" take the viewer to places such as the Cavendish Laboratory, Fermilab, IBM and Oak Ridge Laboratories as well as others. Available through Hawkhill, Madison, WI ($129.00) and includes a *Powerbook* for students.

The Atom - Future Quest, VHS, 27 minutes, color, 1992.

Physicists from the world's premier center for atomic research, Fermilab, discuss the future of atomic studies. Includes discussion of basic questions in cosmology as well as spin-offs from superconductivity, supercomputers and more. Available through Hawkhill, Madison, WI ($69.00) and includes a *Powerbook.*

Creation of the Universe, VHS, 90 minutes, color, 1986.

Explains our ideas about the origin and evolution of the universe in everyday terms with interviews with Stephen Hawking and Allan Sandage, among others. Available through Friends of Fermilab at a cost of $15.00 which includes a teacher and student guidebook. Videodisc is available through the Astronomical Society of the Pacific ($49.95).

Particle Detectives, VHS, 26 minutes, color, 1987.

Explanation and tour of Fermilab with two physicists interacting with three junior high school students. Contents are divided into five 3- to 5-minute segments covering accelerators, the Rutherford Experiment and detectors as well as other concepts. Available through Friends of Fermilab at a cost of $10.00.

Powers of Ten, VHS, 21 minutes, color, 1978.

A classic. A narrated journey into space where every step propels you ten times farther outward. After reaching clusters of galaxies, you return to Earth and travel into the microscopic realm until you reach the nucleus of an atom. Available locally with a $10.00 deposit on loan from the Lederman Science Center. May be purchased from the Astronomical Society of the Pacific in video ($39.95) or Videodiscover, Inc., Seattle WA videodisc ($99.00). This video may also be available for borrowing through AVID or your local library system. University of Illinois Film and Video Center rents this video for $17.00.